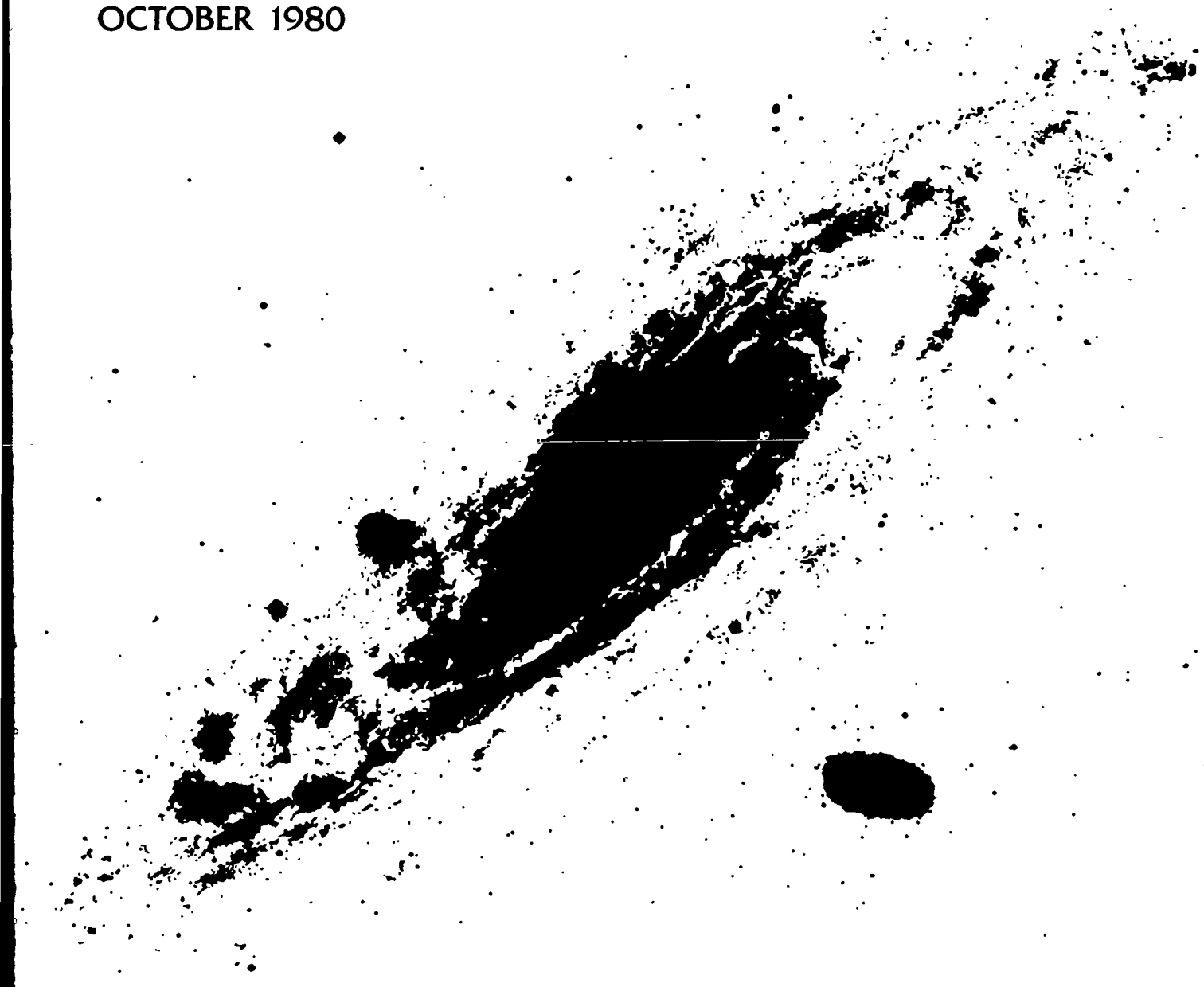
NASA
National Aeronautics and
Space Administration

ASTROPHYSICS NEAR-TERM PROGRAM

PROJECT CONCEPT SUMMARY:

Cosmic Background Explorer (COBE)

OCTOBER 1980



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FOREWORD

This document is one in a series describing projects of current interest in NASA astrophysics planning. Some of these projects were originally suggested by the Space Science Board of the National Academy of Sciences and the Outlook for Space Study Group. Others have been suggested by various internal working groups. Still others have been suggested by individual scientists or scientific groups both within NASA and in the broad astrophysics community. The descriptions presented in these volumes are based on technical studies or preliminary assessments done by NASA's Ames Research Center, Goddard Space Flight Center, Marshall Space Flight Center, and the Jet Propulsion Laboratory. Since the projects are at various stages in the planning process, the level of detail presented gives our current best estimate of the scientific objectives and technical characteristics. Where variations such as alternative strawman payload combinations have been studied, these are presented, and their effects on the overall project are discussed. Specific spacecraft, and other systems or subsystems, are identified or implied in many cases to illustrate that a concept for conducting the project exists. Such identification does not reflect a commitment on the part of NASA to utilize such hardware should the project be implemented. Similarly, in the actual implementation of any particular project, details will inevitably change. Our objective in assembling these documents has been to produce a set of concise project descriptions in a uniform format. They are intended to serve as a basis for discussion within the astrophysics community and to help determine how individual missions can best be accommodated within NASA's overall astrophysics program.

This document was prepared by Dr. John Mathers (Study Scientist) and Gerald Longanecker (Study Manager) of the Goddard Space Flight Center.

Franklin D. Martin

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Director, Astrophysics Division
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COSMIC BACKGROUND EXPLORER (COBE)

PROGRAM SUMMARY:	Explorer Mission Integrated Multiple Experiment Payload
LAUNCH DATE:	Approximately 4 years after program start
MISSION LIFETIME:	1 year
MASS ESTIMATES:	Spacecraft: 737 kg Instrument: 684 kg
FINAL ORBIT:	Altitude: 900 km circular Inclination: 99° Sun synchronous
LAUNCH VEHICLE:	Western Test Range (WTR) Shuttle

OBJECTIVE:

To further the knowledge of science in the area of observational cosmology by making definitive measurements of the cosmic background. Specifically it will:

a. Measure the spectrum of the 3 K cosmic background over wavelength range 100 μm to 1 cm

b. Measure the isotropy of the 3 K cosmic background over the wavelength range 3.3 to 13 mm

c. Measure the spectrum and angular distribution of diffuse infrared background radiation at wavelengths from 1 to 300 μm.

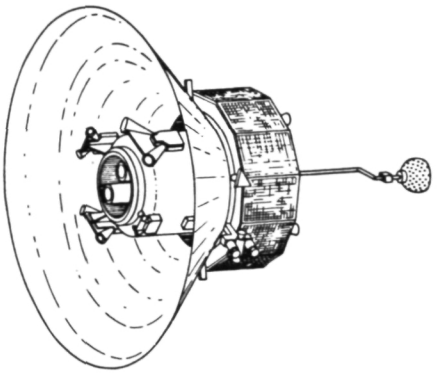
TYPICAL INSTRUMENTS:

a. Far Infrared Absolute Spectrophotometer*

b. Four Differential Microwave Radiometers

c. Diffuse Infrared Background Photometer*

*Cooled to 2 K in a liquid-helium cryostat.



MISSION DESCRIPTION:

The Cosmic Background Explorer (COBE) will be launched from the Western Test Range (WTR) on the Space Shuttle and placed in a 300-km, 99° inclination orbit. On-board propulsion will boost it to 900 km. Communications for commanding and data acquisition will be accomplished using the Tracking and Data Relay Satellite System (TDRSS).

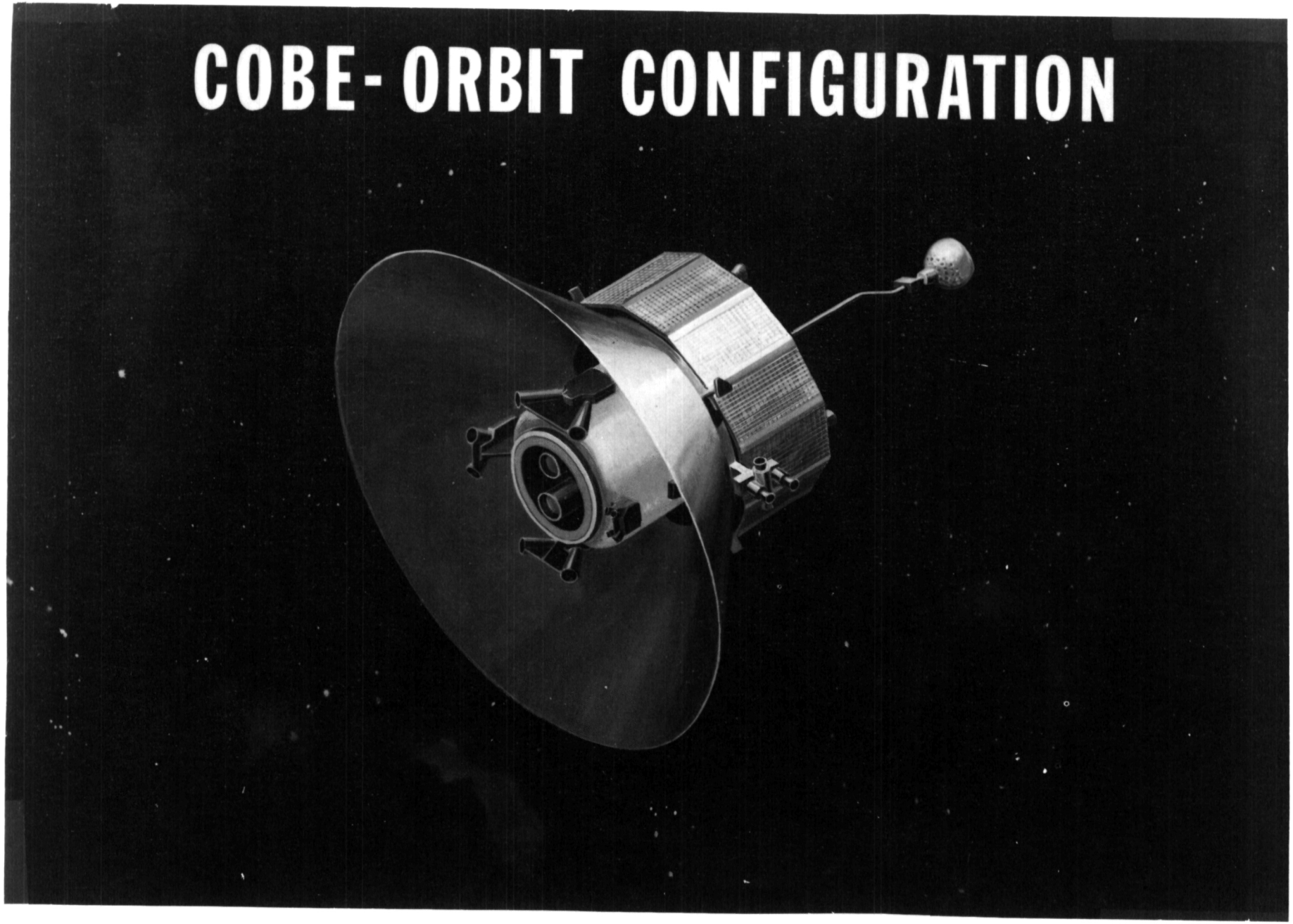
DATA:

The basic results of the COBE mission will be a set of all-sky maps of the diffuse infrared and microwave background radiation at wavelengths from 1 μm to 1.3 cm. The maps will be on an angular scale of 1° and 7°.

STATUS:

The preliminary study phase for the COBE mission has been completed and the definition phase is well advanced. All elements are technically feasible with low risk. The liquid-helium Dewar is perhaps the most difficult new technology and current plans call for COBE to use the Dewar developed for the Infrared Astronomy Satellite to minimize this risk.

COBE-ORBIT CONFIGURATION



SCIENCE

Rationale

The diffuse, large angular scale, electromagnetic emissions from the universe, as a whole, are a unique tool for study of the origin and structure of the universe. They enable us to see much farther in distance, and much farther back in time, than do conventional astronomical methods. Study of this emission began in 1965 with the discovery of the 3 K cosmic background radiation. Almost immediately this emission was interpreted as the radiation from the primeval explosion that started the expanding universe, the Big Bang. This discovery catapulted cosmology from a sleepy and speculative subject into the forefront of research in physics and astronomy. However, despite great efforts, our knowledge of the radiation is still primitive because of the difficulty of observing through the Earth's atmosphere. Balloon and rocket experiments are limited by residual atmosphere, short observing time, and low sky coverage. A satellite such as COBE does not suffer these observational difficulties.

Objectives

Diffuse infrared and microwave radiation arises from many processes. The COBE will make observations in sufficient detail to distinguish the contributions from these sources, by analysis of the particular spectral, spatial, and polarization characteristics of the radiation. Estimates of the brightnesses of these sources are given in Figure 1. In order of decreasing wavelength, we expect to see galactic synchrotron radiation, galactic thermal bremsstrahlung from regions of ionized hydrogen, the 3 K cosmic background radiation from the Big Bang, cold galactic dust (15 K), galactic dust heated by stars (100 K), infrared galaxies, primeval galaxies, interplanetary dust (300 K), and starlight (3000 K). The 3 K cosmic background and the interstellar and interplanetary dust are expected to be dominant between 5 mm and 5 cm.

The general types of questions COBE addresses are:

What is the structure and scale of the universe? When did it begin? Was it turbulent, and, if so, how much and when, and how did the turbulence influence galaxy formation and present distributions of matter? Does the universe rotate or have shear, and does it expand uniformly in all directions?

Is our general Big Bang picture accurate, or is some radically different idea needed? Alternatives include variable constant theories, and Hoyle's steady state models.

What is the distribution, composition, size range, and temperature of the interstellar dust? The interplanetary dust? Are they the same composition? What is the origin of the dust?

Because of COBE's sensitivity, it will also help to answer the following types of questions:

How did galaxies form, and when? What was their luminosity, and spectrum, and how did they evolve with time?

What is the galactic distribution of electrons, what are the electrons' velocities, and what is the magnetic field of the galaxy? How do H II regions emit at high radio frequencies?

Where is the stellar luminosity of our galaxy located?

Further information on the scientific goals of COBE is contained in Ref. 1.

Measurements Required

The COBE will make all-sky maps of the diffuse infrared and microwave background radiation over the wavelength range from 1 μm to 13 mm. The general approach is to measure every relevant factor about the diffuse infrared and microwave background radiation to a precision that is limited only by our understanding of competing astrophysical processes. Specifically, the COBE will:

a. Measure the spectrum of the background radiation near the 3 K blackbody peak to very high precision. This is needed because while theory predicts that only very small deviations from a perfect blackbody spectrum are expected, if they do exist they are extremely important.

b. Measure the angular distribution of the 3 K background radiation to extremely high precision at microwave frequencies where other sources are weakest. This is important because the radiation is observed to be nearly uniform, although even very small anisotropies are highly significant. Measurements at several frequencies are needed to identify the source of any observed nonuniformity.

c. Measure the spectrum and angular distribution of the emission from interstellar dust, peaking near 200 μm wavelength. This is important for Item (a) because there is a residual emission from the dust emission that overlaps the 3 K background.

d. Measure the spectrum and angular distribution of the interplanetary dust, peaking near 10 μm.

e. Determine the components of diffuse radiation due to other, weaker sources, such as galactic synchrotron radiation and bremsstrahlung, primeval and infrared galaxies, and starlight.

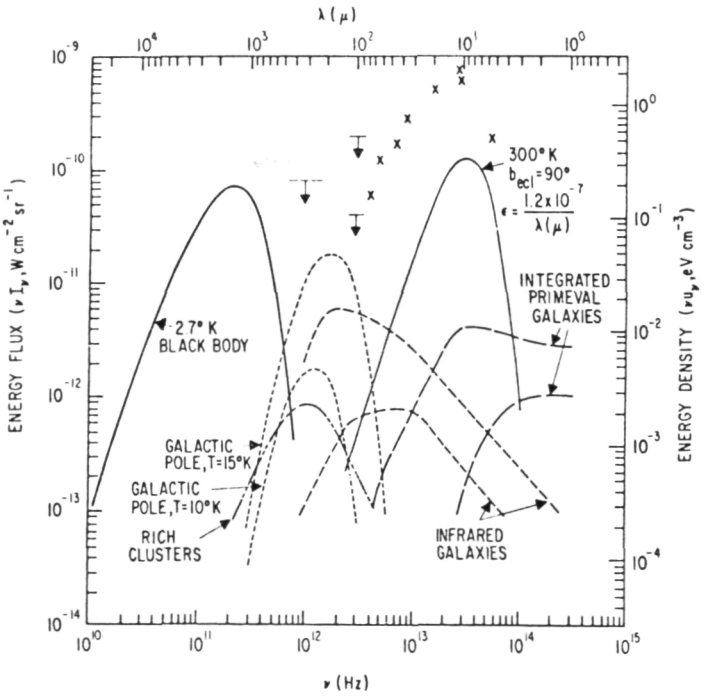


FIGURE 1. Brightnesses of radiation sources.

Typical Instrument Payload

A baseline instrument package to meet these objectives was described in the COBE Interim Study Report, February 1977.[1] Two of the instruments operate at a temperature of 2 to 3 K in a liquid helium cryostat, with the same parameters as the Infrared Astronomy Satellite (IRAS) cryostat. The instruments are all based on equipment which has flown successfully on balloons, rockets, and aircraft.

Figure 2 is a drawing of the instrument complement and the spacecraft systems. The cryostat with its two infrared instruments is located in the center of a conical Earth and Sun shield and ground plane. Four microwave radiometers are distributed around the cryostat, inside the Sun shield. A far-IR spectrophotometer looks along the cryostat axis, while the microwave instruments and a diffuse IR photometer view 30° off axis. The spacecraft rotates at 1 rpm to scan the off-axis beams rapidly across the sky and to ensure thermal stability of the microwave instruments. The orbit, a Sun-synchronous terminator orbit, is chosen to keep the Sun always to the side of the spacecraft and the Earth always below, so neither can ever illuminate the instruments or cryostat. This also allows the spin axis to sweep the entire sky twice in 1 year.

a. Far Infrared Absolute Spectrophotometer (FIRAS)

° Polarizing Michelson Interferometric spectrometer

° Wavelength range 100 μm to 1 cm.

° 7° field of view (FOV)

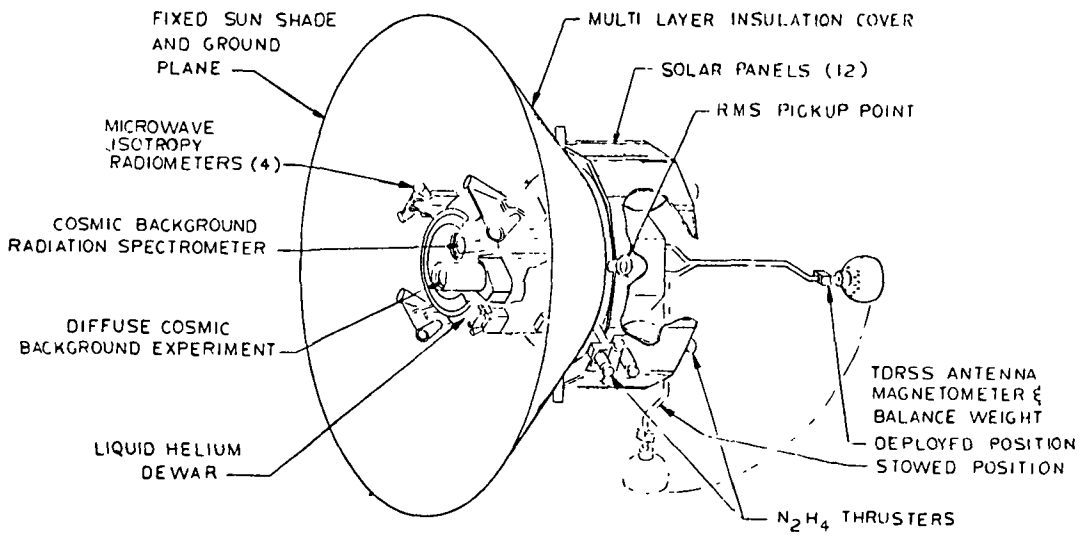


FIGURE 2. Cosmic Background Explorer spacecraft instruments.

° Frequency resolution 5 percent, but limited to 0.2 cm^{-1}

° Full-beam absolute calibration by an external blackbody

° Differential comparison of input spectrum to an internal 3 K blackbody

° Sensitivity 2 x 10^{-14} W/cm^2 sr per FOV and frequency resolution element

° Instrument temperature 2 K

° Composite bolometer detectors

° Flared trumpet horn flux collector

° 46 kg, 18 W, 1100 bps.

This instrument is capable of measuring the spectrum to a precision of 1/1000 of the peak flux at 6 cm^{-1}, for each of 1000 fields-of-view on the sky.

b. Differential Microwave Radiometers (DMR)

° Dicke-switched two horn microwave receivers

° 23.5, 31.4, 53, and 90 GHz frequencies, dual polarization

° Dual 7° FOV, 30° off spacecraft axis

° Sensitivity 0.0003 K for each FOV, 1/10,000 of background temperature

° Temperature 300 K, well regulated

° Diode mixer front ends

° Requires 1 rpm spinning spacecraft

° 50 kg, 65 W, 500 bps.

c. Diffuse Infrared Background Photometer (DIRBP)

° Well-baffled, off-axis Gregorian flux collector with reimaging

° 1 to 300 μm wavelength, in 10 bands: photometry bands J, K, L, M, the four IRAS bands, and two long wave bands

° FOV 1°, 30° off the spacecraft axis

° Sensitivity 1 x 10^{-13} W/cm^2 sr for each FOV

° Polarization measured in bands J and K

° Total beam chopping and absolute calibration

° Photoconductor detectors for wavelengths below 200 μm; composite bolometers for wavelengths above 200 μm

° Temperature 2 K

° 18 kg, 15 W, 2000 bps.

MISSION DESCRIPTION

General

A single spacecraft will be placed in a 900-km altitude, Sun-synchronous terminator orbit by an integral hydrazine propulsion system, starting from a West Coast Shuttle parking orbit of 300-km, 99° inclination. The TDRSS will support the mission from launch through separation from the Space Shuttle. Thereafter, the TDRSS and a Project Operations Control Center (POCC) will be utilized for control of the satellite and for retrieval of scientific data. About 12 hr of multiple access TDRSS coverage is required per day. The orbit is computed from the TDRSS tracking data. Attitude is determined from Sun and Earth sensors. These data will be captured at the GSFC and will be quality checked and formatted prior to distribution to the Principal Investigators for reduction and analysis.

A committee composed of all the Principal Investigators and the Project Scientist will define the observing program, which will be executed through the POCC.

SPACECRAFT CHARACTERISTICS

General

The total mass of the COBE spacecraft is expected to be about 1421 kg. The scientific instruments and the Dewar will weigh about 684 kg, with the spacecraft systems making up the balance of 737 kg.

Instrument Characteristics

Two of the three instruments are contained within a Dewar filled with about 70 kg of 2 K superfluid helium. The Dewar is nearly identical to the one to be flown on IRAS. These instruments are the Far Infrared Absolute Spectrophotometer and the Diffuse Infrared Background Photometer. The other instrument is mounted around the periphery of the Dewar and consists of four dual-horn microwave radiometers. The center line of the liquid-helium Dewar is located along the 1-rpm spin axis. The instruments and the Dewar are shielded from Earth and Sun radiation by a combination Sun shade/ground plane. The orientation of the spin axis is maintained anti-Earth and nominally at 94° to the Sun line. The orbit and orientation provide complete coverage of the entire celestial sphere twice in the nominal 1-year lifetime of the liquid helium. The spin and symmetrical configuration eliminate local thermal effects that could bias the data.

Spacecraft Systems

A basic spacecraft of the Applications Explorer Mission class may be used for COBE. Detailed spacecraft requirements and design are now being studied. The spacecraft provides the instrument with power, telemetry, and commands. It also maintains the pointing vector and 1-rpm spin, so that the sky coverage of the instruments is as desired. A propulsion system boosts the orbital altitude of the COBE from a Shuttle parking orbit of 300 km to an operational orbit of 900 km. This system is completely shut off during science operations because the propulsion gases would condense and freeze on the instruments and block their operation. The power subsystem consists of 12 fixed solar array panels. A 385-W orbit average can be maintained. The Communications and Data Handling (C&DH) System provides control of all spacecraft and instrument functions. It collects telemetry data from the instruments and the spacecraft and either transmits them in real time via TDRSS to the ground or stores the data on a tape recorder for later transmission. A NASA standard TDRSS Transponder is used for the RF functions of command, telemetry, and tracking. A boom-mounted, S-band phased array, 13-dB gain antenna is deployed on the spin axis of the spacecraft. The spacecraft systems will be designed to give a minimum of thermal input into the instruments. Low conductance supports and multilayer insulation will be used between these components.

Ground Data Handling System

The data will be transferred to the GSFC by NASCOM and will be put on a computer tape by the Telops data system. The TDRSS tracking data will be processed at the GSFC and a definitive orbit tape made. These tapes can be processed by the same computer as that used during integration and test of the COBE spacecraft. This would maximize the utilization of existing programming. The processing involves calibration corrections, averaging, and gridding.

DATA

The basic results of the COBE mission will be a set of all-sky maps of the diffuse infrared and microwave background radiation at wavelengths from 1 μm to 1.3 cm. The maps will be on an angular scale of 1° and 7°.

MISSION OPTIONS

The baseline mission is a launch on the West Coast Shuttle. A possible optional launch vehicle would be the West Coast two-stage Delta. A folding Sun shield/ground plane can be made to allow fitting within the Delta shroud. Everything else will fit without change.

PROGRAM ASSESSMENT

None of the payload experiments described herein exceeds the current state of technology.

TECHNOLOGY READINESS/TECHNOLOGY DEVELOPMENTS NEEDED

The technology for COBE is in a high state of readiness and requires little development. Even the liquid-helium Dewar that is required for two of the instruments is under development for the IRAS program. The instruments are all derived from instruments that have flown on balloon, aircraft, and/or sounding rockets. The spacecraft components are well within today's art.

Reference

1. COBE Interim Study Report, February 1977, available from John Mather, Code 693, Goddard Space Flight Center, Greenbelt, Maryland 20771.